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Estimating stand-level economic impacts of black bear damage to intensively managed forests

Kristina N. Kline, Jimmy D. Taylor, and Anita T. Morzillo

Abstract: Black bears (*Ursus americanus* Pallas, 1780) peel conifers in early spring to forage on energy-rich vascular tissues, resulting in damage to timber stands. The objective of our study was to develop and demonstrate a conceptual framework and methods for estimating stand-level volume and economic losses from black bear damage. We created tree lists from surveys of healthy and bear-damaged trees in timber stands of western Washington and Oregon. The forest growth model Forest Vegetation Simulator (FVS) was used to project stand volume under two damage scenarios and an undamaged scenario. One damage scenario (salvage) accounted for mortality and volume losses of fully and partially girdled trees; a second scenario (total loss) assumed complete loss of all trees peeled by black bears, regardless of peeling severity. The Fuel Reduction Cost Simulator (FRCS) was applied to estimate the value of logs delivered to the mill after accounting for logging and hauling costs associated with harvest. Present value of stands was calculated to translate volume losses into economic losses associated with bear damage. Economic losses ranged from 4% to 16% (salvage) and from 17% to 46% (total loss) of net present value. Our approach can be adapted for other forest settings and for forest management plans that assess wildlife damage.

Key words: black bear, Douglas-fir, economic impacts, peeling, timber damage.

Résumé : L'ours noir (*Ursus americanus* Pallas, 1780) arrache l'écorce des conifères tôt au printemps pour se nourrir des tissus vasculaires riches en énergie et cause des dommages aux peuplements forestiers. L'objectif de notre étude consistait à élaborer et présenter un cadre conceptuel et des méthodes pour estimer à l'échelle du peuplement les pertes de volume ainsi que financières dues aux dommages causés par l'ours noir. Nous avons créé des listes d'arbres sains et d'arbres endommagés par les ours à partir des inventaires de peuplements forestiers de l'ouest des États de Washington et de l'Oregon. Un modèle de croissance de la forêt, le simulateur de végétation forestière, a été utilisé pour prévoir le volume d'un peuplement selon deux scénarios comportant des dommages et un troisième qui n'en comporte pas. Un scénario comportant des dommages (récupération) tenait compte de la mortalité et des pertes de volume des arbres partiellement et complètement annelés; un second scénario (perte totale) assumait la perte complète de tous les arbres endommagés par les ours noirs, peu importe la sévérité des dommages. Le simulateur du coût de réduction des combustibles a été appliqué pour estimer la valeur des billes livrées à l'usine après avoir pris en compte les coûts de la coupe et du débardage associés à la récolte. La valeur actualisée des peuplements a été calculée pour traduire les pertes de volume en pertes financières associées aux dommages causés par les ours. Les pertes financières variaient de 4–16 % (récupération) et de 17–46 % (perte totale) de la valeur actualisée nette. Notre approche peut être adaptée à d'autres situations ainsi qu'aux plans d'aménagement forestier qui évaluent les dommages causés par la faune. [Traduit par la Rédaction]

Mots-clés : ours noir, douglas de Menzies, impacts économiques, écorçage, dommages aux bois.

Introduction

American black bears (*Ursus americanus* Pallas, 1780) damage trees after canopy closure in intensively managed forests of the Pacific Northwest, peeling bark from conifers in early spring to forage on phloem and cambial tissues (hereafter vascular tissues). These tissues provide energy-rich soluble sugars for black bears at a time of year when similarly attractive energy sources such as salmonberry (*Rubus spectabilis*), red huckleberry (*Vaccinium parvifolium*), and blackberry (*Rubus ursinus*) are scarce. The presence of up to 3.5% soluble sugars in the phloem of trees at this time of year provides fructose, sucrose, and glucose, which help black bears meet their energy needs following winter dormancy (Kimball et al. 1998a, 1998b; Radwan 1969; Ziegler 2004). Although first

reported in the early 1900s (Pierson 1966), it was not until the increase in intensive forest management in the 1940s that bark peeling by black bears was identified as a problem for timber production in the Pacific Northwest (Pierson 1966).

In western Oregon and Washington, black bears typically damage Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) trees in stands that are intensively managed for timber production (Schmidt and Gourley 1992). Management activities such as thinning and fertilization increase tree growth and volume, which in turn increase sugar concentrations in vascular tissues (Kimball et al. 1998b). This makes trees more attractive as forage to black bears. Peeling occurs at varying severities, which result in a variety of damage impacts. A tree will eventually die if fully girdled (i.e., peeled around the entire circumference of the trunk). A tree that is par-

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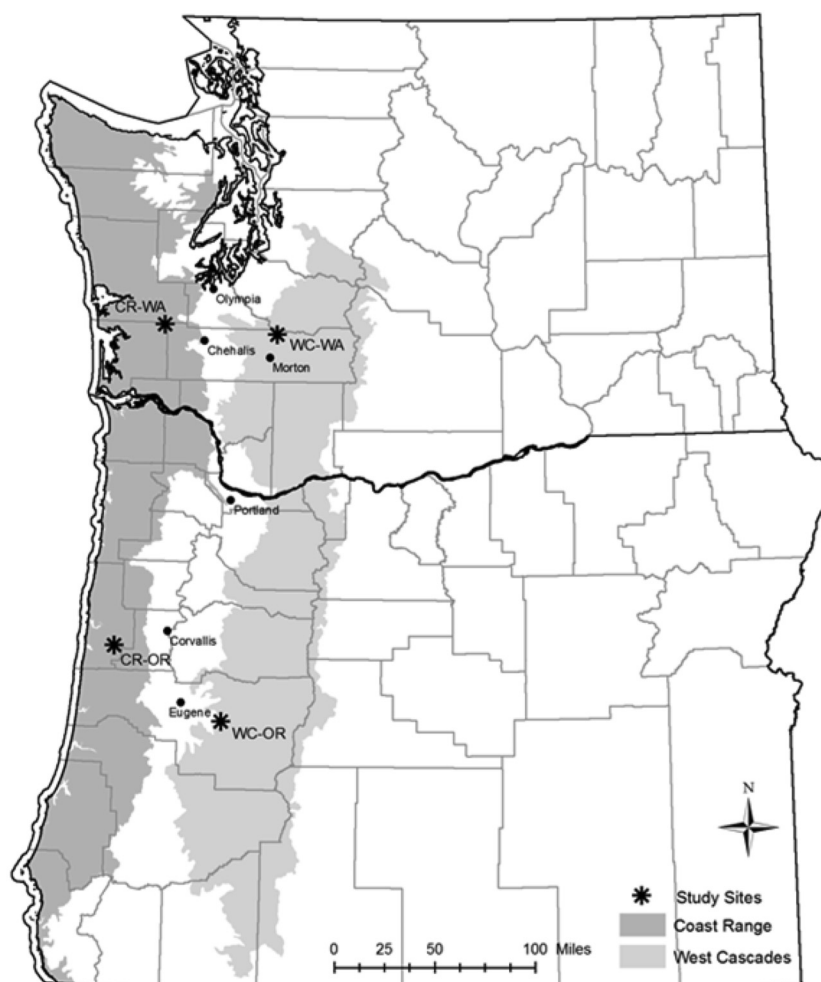
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Fig. 1. Locations of the four study sites in the western Cascades and Coast Range of Oregon (CR-OR and WC-OR) and Washington (WC-WA and CR-WA).



tially girdled becomes more susceptible to insect infestations, fungal decay (Kanaskie et al. 1990), and windfall (Witmer et al. 2000), thereby reducing the likelihood of surviving to harvest age. Miller et al. (2007) evaluated survival of trees damaged by black bears in Washington and reported mortality rates of 17% for partially girdled trees over a 16-year period. An ongoing, long-term study of simulated bole damage in Capitol Forest, Washington, reported mortality rates of between 5% and 28% for partially girdled trees, with mortality rates increasing with the percentage of the bole circumference damaged (Connie Harrington, USDA Forest Service, unpublished data). Partially girdled trees that survive to harvest age also may experience a reduction in the volume of merchantable timber produced (Lowell et al. 2010; Pierson 1966).

To our knowledge, only two studies have quantified timber volume losses due to black bear damage. In a survey of black bear damaged trees sent to mill in Washington, Lowell et al. (2010) found a 6.4% loss in volume, on average, for trees partially girdled as a result of black bear damage. Additionally, Lowell et al. (2010) found the value of such partially girdled trees was 5% less than undamaged trees. Elsewhere, Pierson (1966) reported average volume losses from a survey of 100 Douglas-fir trees with varying damage severities. Trees with bark removed from less than 50% of the trunk circumference lost an average of 7% merchantable volume, while trees with bark removed from more than 50% of the trunk circumference lost an average of 10% merchantable volume (Pierson 1966). While informative, these studies are limited to a focus at the scale of individual trees.

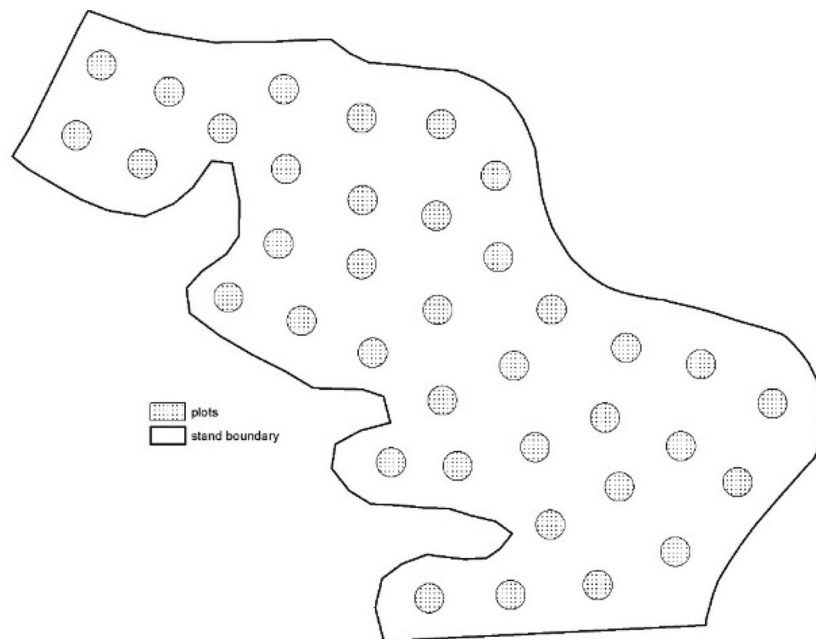
Our objective was to further our understanding of black bear damage to timber stands by developing and demonstrating a conceptual framework and methods for estimating stand-level volume losses and economic losses from black bear damage. Previous studies on economic impacts of black bear damage to trees focused at the regional level and used aerial counts of conifers with red crowns as an index of bear damage (Nolte and Dykzeul 2002; Taylor et al. 2014). Aerial estimates may overestimate bear damage because other sources such as root rot cause red crowns (Kanaskie et al. 1990). They also may underestimate black bear damage because partial peeling affects wood quality but does not cause crowns to turn red (Kanaskie et al. 1990). Therefore, our study builds upon previous research by addressing volume losses to black bear damage at the stand level in three ways: (i) including the impacts of volume lost from partially girdled trees, (ii) accounting for volume lost in relation to the severity of individual-tree damage, and (iii) accounting for stand growth and yield projected to harvest.

Methods

Study sites

Study sites consisted of four intensively managed Douglas-fir stands on private land within the Coast Range and the western Cascades of Oregon (OR) and Washington (WA) (Fig. 1). The western Cascades ecoregion consists of a mild maritime climate with cool, wet winters and hot, dry summers (Immell et al. 2013). Aver-

Fig. 2. Illustration of arrangement of 0.04 ha circular plots. Plots were evenly spaced across each stand in a grid-like system.



age annual rainfall ranges from 107 to 226 cm and average annual snowfall ranges from 18 to 592 cm occurring above 1220 m (Oregon Department of Fish and Wildlife 2006). Stands were dominated by Douglas-fir, with co-dominants including western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), western redcedar (*Thuja plicata* Donn ex D. Don), and red alder (*Alnus rubra* Bong.). Understory vegetation was comprised of salmonberry (*Rubus spectabilis*), vine maple (*Acer circinatum*), swordfern (*Polystichum munitum*), foxglove (*Digitalis purpurea*), Oxalis (*Oxalis oregana*), Oregon grape (*Mahonia nervosa*), snowberry (*Symphoricarpos albus*), devil's club (*Oplopanax horridus*), stinging nettle (*Urtica dioica*), Trillium (*Trillium ovatum*), lady fern (*Athyrium filix-femina*), pacific bleeding heart (*Dicentra formosa*), and miner's lettuce (*Claytonia perfoliata*).

The Coast Range ecoregion consists of a maritime climate, with mild, wet winters and warm, dry summers (Cushman and McGarigal 2003). Average annual precipitation ranges from 152 to 249 cm (Oregon Department of Fish and Wildlife 2006). Stands are dominated by Douglas-fir, with co-dominants including western hemlock, western redcedar, and red alder. Understory vegetation was comprised of salmonberry, salal (*Gaultheria shallon*), vine maple, swordfern, foxglove, Oxalis, Oregon grape, and snowberry.

Stands were even-aged plantations and managed for timber production using intensive silvicultural practices. Characteristics varied by stand, and each stand was considered by managing foresters to contain high levels of black bear damage. The WA Coast Range site (CR-WA) was located in Pacific County, approximately 1 km south of the Lower Chehalis State Forest. The western Cascades site in WA (WC-WA) was located in Lewis County, approximately 1 km north of the Gifford Pinchot National Forest. These stands had not been pre-commercially thinned.

The OR Coast Range site (CR-OR) was located in Lincoln County, approximately 1 km east of the Siuslaw National Forest. This stand was pre-commercially thinned at age 13 years to a density of 733 trees per hectare. The western Cascades site in OR (WC-OR) was located in Lane County, approximately 1 km north of Oregon Department of Forestry (ODF) land. This stand was pre-commercially thinned at age 14 years to a density of 650 trees per hectare.

Sampling design

We collected data in June 2015, and sampled 10% of each stand. We used fixed 0.04 ha circular plots to survey each stand. With fixed circular plots, we were able to observe the full circumference of each tree, ensuring that all damage was captured regardless of where the damage occurred on the tree.

We evenly spaced plots at 50 m throughout the stand in a grid-like arrangement (Fig. 2). Within each plot, we measured diameter at breast height (DBH) of every tree with a DBH > 10 cm. We measured height and height-to-live-crown-base (HCB) of every 10th tree, as well as every black bear damaged tree. For trees damaged by black bear, we noted the condition of the crown (red, yellow, green, or no needles) and measured the percentage of the circumference peeled.

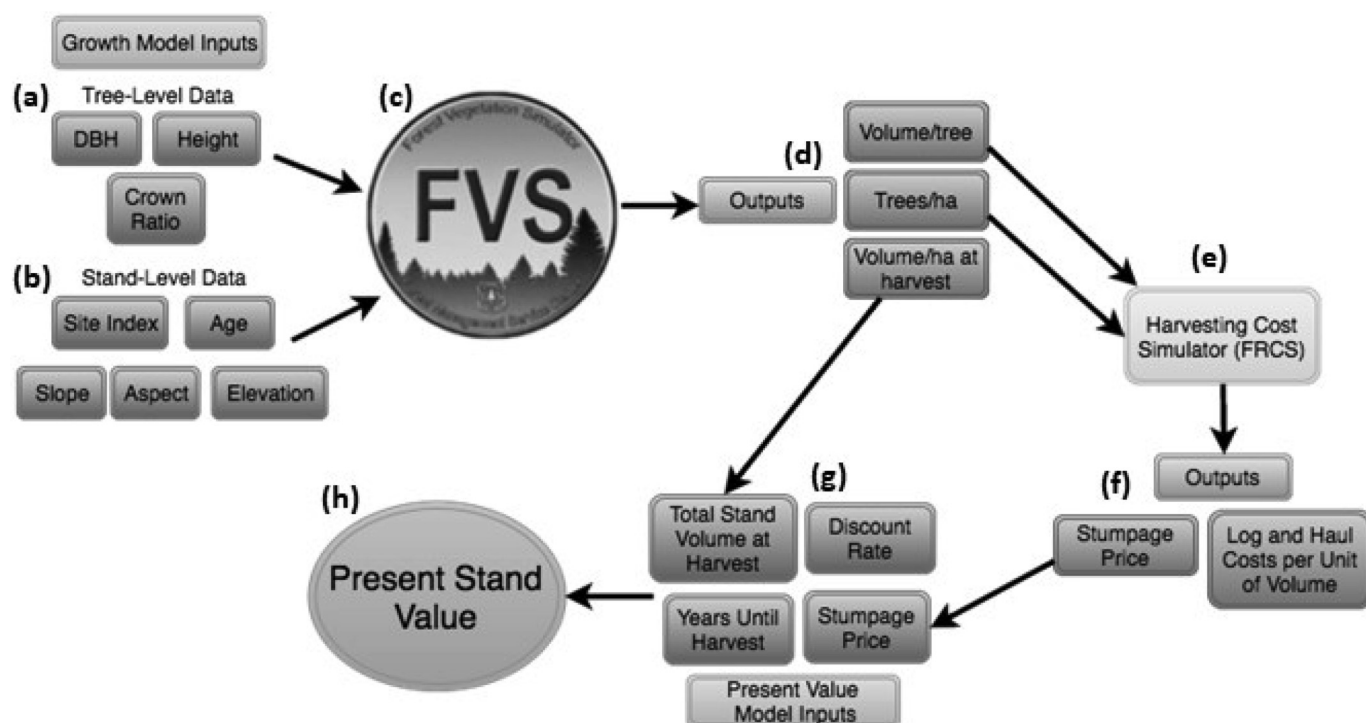
Imputation of tree-level attributes

Imputation of values for certain tree-level attributes such as height is a necessary component of forest inventory (Garber et al. 2009). Measuring heights of all individual trees is a time-consuming task (Wang and Hann 1988) and imputation greatly increases the efficiency at which a stand can be sampled. Additionally, forest modeling requires height estimates for every tree to calculate volume. Height imputations involve the use of both DBH and height variables, as a strong relationship exists between the two (Curtis 1967). For each stand, we used the following height-diameter equation, which is commonly used in the Pacific Northwest, to relate tree height to DBH and impute missing heights (for details, see Curtis 1967):

$$(1) \quad H = 1.37 + \beta_1 \exp\left(\frac{\beta_2}{\text{DBH}}\right) + \varepsilon_1$$

where H is the height of the tree (in metres), 1.37 is the above-ground height (in metres) at which DBH is measured, \exp is the base of the natural logarithm, DBH is the diameter at breast height of the tree (in centimetres), β_1 and β_2 are parameters to be estimated from the data, and ε_1 is the residual error with $\varepsilon_1 \sim N(0, \sigma_1^2)$. Derived from equations fit with our field data, β_1 was the upper asymptote for predicted heights, and β_2 determined the

Fig. 3. Flowchart illustrating various growth model and economic model inputs and outputs for simulating impacts of bear damage to private timberlands in western Oregon.



shape of the approach to this upper asymptote. We then log transformed this equation to obtain initial parameter estimates through simple linear regression. Due to differences in tree density and stand structure, we fit individual equations for each stand. We completed all statistical analyses using SAS software (version 9.2; SAS Institute Inc. 2011).

To impute missing height-to-live-crown-base (HCB) measurements, we used the following equation:

$$(2) \quad \text{HCB} = \beta_1 \exp\left(\frac{\beta_2}{\text{DBH}}\right)$$

where HCB is the height from the base of the trunk to the base of live crown (in metres), and exp and DBH are as previously defined. Data used to fit the models were limited to living trees only, as dead trees had no HCB values. For all stands, the β_1 and β_2 parameters for damaged and undamaged trees, respectively, were the same.

Estimating stand volume and economic value

For analysis of bear damage impacts, we used a combination of existing models to estimate forest growth and yield, harvest costs, and present value (Fig. 3). We first transformed tree-level data (Fig. 3a) into tree lists to construct stand-level projections (Fig. 3b). Tree lists consisted of the following tree-level variables: tree number, species, DBH, height, crown ratio, and expansion factor. We calculated crown ratio by subtracting the HCB from the full height of the tree to obtain the crown height and then dividing the crown height by the full height of the tree. We calculated expansion factor (the number of trees per hectare that a given plot tree represents) by taking the denominator of the plot size (same for all stands), which was 0.4 ha or 1/10 acre, and dividing it by the number of plots sampled in that stand. For example, in our stand with 37 plots, the expansion factor was 2.07 (10/37). Following that, we input tree lists for each stand into the Forest Vegetation Simulator (FVS) growth and yield model (Fig. 3c; Dixon 2002)

within the Landscape Management System (LMS) interface, version 2.1 (Nelson et al. 1999). FVS is a distance-independent, individual-tree growth and yield model (Dixon 2002) capable of simulating a wide range of silvicultural treatments for most tree species, forest types, and stand conditions (Teck et al. 1997; Crookston and Havis 2002; Crookston and Dixon 2005; USDA Forest Service 2016). While Ceder and Marzluff (2002) used FVS with the LMS interface to evaluate wildlife habitat, our use of FVS within LMS was consistent with traditional harvest planning (Crookston and Dixon 2005). We used the Pacific Northwest Coast (PN) variant of FVS for Coast Range sites and the West Cascades (WC) variant for western Cascades sites. Both are accepted methods in the Pacific Northwest region and applicable to the Douglas-fir stands of focus in this study (Dixon 2002).

Use of alternative scenarios in ecological and economic modeling is useful for exploring the range in plausible outcomes in the face of uncertainty (Francis and Hamm 2011). In our study, we developed two scenarios to explore estimated loss in timber volume due to black bear damage in each stand. In this first scenario, we assumed that a percentage of partially girdled trees would die, conditional on the severity of damage. For individual trees that survived, we assumed that a percentage of volume would be lost (7%–10%; Pierson 1966), also conditional on the severity of damage. Under scenario 1, damaged trees with standing live volume were harvested and processed, thus we refer to this as the “salvage” scenario. We acknowledge that the term salvage in forestry commonly refers to a logging operation following a larger natural disturbance (e.g., fire, ice damage, windstorm). In this case, we apply the term in a similar fashion to account for removal and processing of all merchantable value from black bear damaged trees. We based scenario 2 on personal communications with some of our cooperating landowners who felt that bear-damaged trees provided no economic return. In this second scenario, any black bear damage resulted in a complete loss of the damaged tree’s volume, regardless of whether the tree was partially girdled or killed. We assumed that the costs required to salvage a black

bear damaged tree at harvest offset any profit that would be made from the tree, resulting in zero monetary value gained from harvest. Thus, we referred to this as the “total loss” scenario.

Salvage scenario

To account for tree mortality and individual-tree volume loss due to bear peeling in the growth and yield model under this scenario, we applied Connie Harrington’s estimates (USDA Forest Service, unpublished data) of percent mortality and Pierson’s (1966) estimates of volume lost at the tree level to our field data. Harrington’s estimates (USDA Forest Service, unpublished data) were derived from five different categories of bole circumference damage: 20%, 40%, 60%, 80%, and 90% of circumference. As our categories of damage severity from field data ranged from 10%–100% in 5% increments, we re-categorized them to match those used by Harrington. For trees in the 20%, 40%, and 60% damage categories, Harrington’s cumulative mortality rates leveled off around 6% after 6 years. For our data, we assumed that mortality rates for these three categories (20%, 40%, and 60%) would remain at 6% in the future. We designated this as a single damage category, further referred to as the low-damage category. This category contained all trees with observed damage to $\leq 60\%$ of the circumference. For trees in the 80% and 90% categories, Harrington (USDA Forest Service, unpublished data) showed that mortality rates increased linearly over time. For our data, we assumed that mortality rates in these categories would continue on these linear trajectories into the future. With this assumption, we fit a linear model for each category to estimate mortality rates past 8 years. This was necessary as stands were to be projected in the growth model 15–45 years into the future. The equation fit for the 90% category was

$$(3) \quad m = -17.9750 + 3.6083 \times \text{yr}$$

The equation fit for the 80% category was

$$(4) \quad m = -8.4028 + 1.4583 \times \text{yr}$$

where m represents the percent mortality at harvest age and yr is the number of years since damage occurred. The yr value was obtained by adding the number of years since damage occurred on average in each stand at present to the number of years each stand was to be projected in the growth model. We assigned all trees with observed damage between 60% and 80% of circumference peeled to the 80% category. We assigned all trees with observed damage between 80% and 99% of circumference peeled to the 90% category.

To estimate each stand’s volume, we implemented two thinning treatments in the growth model. We used thinning treatments as a surrogate to simulate black bear peeling, as the model does not contain direct inputs for wildlife damage. In the first thinning, we removed all observed black bear killed trees before growing the stand to harvest age. After we grew each stand to harvest age in the model, we implemented an additional thinning. To implement the second thinning, we calculated the proportion of partially girdled trees in each stand that fell into each of the three damage categories (low damage and 80% and 90% damage). We then removed the percentage of trees in each damage category that would have died over time from black bear damage. We based these removal percentages on mortality rates derived from the linear models that we fit for each stand (Table 1). We identified removal trees by species (Douglas-fir) and DBH (trees with the mean DBH of black bear damaged trees).

To compute losses in volume of surviving partially girdled trees, we calculated the standing volume of all trees remaining at harvest with $\leq 50\%$ of their circumference damaged and then multiplied it by 7% to obtain the first volume reduction value. We then

Table 1. Percent mortality values used for each stand at harvest age, as derived from the percent mortality linear models fit from Connie Harrington’s data (USDA Forest Service, unpublished data).

Stand	Years projected	Percent mortality for		
		80%*	90%†	Low damage‡
CR-WA	45	65	100	6
CR-OR	15	21	54	6
WC-OR	40	54	100	6
WC-WA	30	40	100	6

*Percentage of partially girdled trees with between 60% and 80% of their circumference peeled that would die in each stand after being projected to harvest age. Value derived from the following linear regression equation: $m = -8.4028 + 1.4583 \times \text{yr}$, where m is percent mortality at harvest age and yr is the number of years since damage occurred. $R^2 = 0.9483$.

†Percentage of partially girdled trees with between 80% and 99% of their circumference peeled that would die in each stand after being projected to harvest age. Value derived from the following linear regression equation: $m = -17.9750 + 3.6083 \times \text{yr}$. $R^2 = 0.9771$.

‡Percentage of partially girdled trees with less than 60% of their circumference peeled that would die in each stand after being projected to harvest age.

calculated the standing volume of all trees remaining at harvest with $>50\%$ of their circumference damaged and multiplied the volume of damaged trees by 10% to obtain the second volume reduction value. We added these two volume reductions together and then subtracted the total volume reductions from the total stand volume at harvest to obtain a recoverable stand volume after accounting for black bear damage.

Total loss scenario

To simulate this scenario in the growth model, we implemented two thinning treatments in each stand. In the first thinning, we removed all observed black bear killed trees. We then projected each stand to harvest age and implemented a second thinning. In this second thinning, we removed all remaining partially girdled trees from each stand. We selected removal trees by species (Douglas-fir) and by DBH (trees with the mean DBH of black bear damaged trees). We removed partially girdled trees after each stand was projected to harvest because they are usually left to grow until harvest. In this scenario, they become a complete loss at harvest because the value of recoverable volume is assumed equal to harvesting costs.

Undamaged scenario

We developed an “undamaged” scenario for each stand to serve as a control for comparison of the two damaged scenarios. To simulate undamaged stands, we treated black bear killed trees as undamaged living trees. We originally assigned crown ratio values of zero to black bear killed trees. To include them as living trees, we imputed their crown ratios using the HCB equations described above specific to each stand. We then projected stands to harvest age in the growth model and calculated volume of surviving trees at harvest.

Present stand value

We used the present value of each stand to translate volume losses into economic losses. Present value estimations require knowledge of volume at harvest (Fig. 3d; as obtained from FVS outputs, i.e., Fig. 3c) and the value of logs delivered to the mill (pond value). These estimations also require knowledge of the logging and hauling costs that are subtracted from the value of logs delivered to the mill. To estimate logging and hauling costs associated with each stand at harvest, we input volume at harvest values for each stand under all scenarios into the Fuel Reduction

Cost Simulator (FRCS; Fig. 3e) (Fight et al. 2006), specifically the FRCS-West variant. Data inputs included stand slope, average yarding distance from the stand to a roadside landing, stand area, elevation, harvesting system used, number of large trees per hectare, and mean volume per large tree. We derived large trees per hectare and mean volume per large tree values from FVS output (Fig. 3f) by dividing total volume per hectare by trees per hectare. We derived average yarding distance by measuring the distance from the GIS-calculated centroid of each stand to the nearest road in GIS. Spatial road data were obtained from cooperating landowners. We derived slope values from digital elevation model layers in GIS using the Spatial Analyst Slope Tool.

We performed the FRCS simulation using the special “Billion-Ton” processing rules. These rules designate a harvesting method based on each stand’s slope and volume per hectare. If the slope was $\leq 40\%$, then two alternatives of a ground-based logging system were considered by the model: mechanical whole-tree harvesting with feller-bunchers and skidders used to transport bunches or manual whole-tree harvesting with chainsaws and skidders used to transport whole trees (Dykstra 2010; Fight et al. 2006). FRCS completes calculations for both possible alternatives and selects the lower cost alternative (Dykstra 2010). If the slope was $>40\%$, the simulator used manual felling and cable yarding as the harvesting system (Dykstra 2010). Based on stand slopes, we harvested CR-WA and WC-WA in the simulation using a ground-based mechanical system. We harvested CR-OR and WC-OR in the simulation using a system of manual felling with chainsaws and cable yarding. We simulated all stands as clear-cuts and included loading costs.

The following land expectation value (LEV) equation (Fig. 3g) was applied to estimate the present value of each stand (Fig. 3h) under all scenarios:

$$(5) \quad PV = \frac{V_h \times SP}{(1 + i)^y}$$

where PV is the present value of the stand in US dollars, V_h is the total volume of the stand at harvest age, SP is the stumpage price, which is the pond value (i.e., log value) minus logging and hauling costs, i is the discount interest rate, and y is the number of years from present to harvest age (years projected). To determine an average log value per thousand board feet (MBF), we used output from the growth model to calculate a distribution of volumes by log grade at harvest in each stand. We then calculated a weighted mean log value per MBF based on this distribution for each stand (Table 2). We distributed stand volume among the following six log grades: special mill, #2 sawmill, #3 sawmill, #4 sawmill, chip-and-saw, and pulp logs. We used the most current market value for each grade in the calculation of weighted mean price per Douglas-fir MBF. We used a discount interest rate of 5%, because the most common interest rates used in these calculations are 4%–6% (Darius Adams, Oregon State University, personal communication).

Results

Stand-level inputs differed by site (Table 3) and resulted in different levels of volume at harvest (Table 4). The WC-OR stand contained the highest levels of black bear damage, with 42.4% of the stand damaged. The CR-WA stand contained 16.2% damage, WC-WA contained 13.5% damage, and CR-OR contained 8.5% damage. Volume losses in the salvage and total loss scenarios ranged from 4% to 15% and 16% to 43%, respectively (Table 4). Volume losses in the total loss scenario were, on average, four times greater than volume losses in the salvage scenario. Economic losses in the salvage scenario ranged from US\$472-ha⁻¹ to US\$1635-ha⁻¹, while economic losses in the total loss scenario ranged from US\$2416-ha⁻¹ to US\$4978-ha⁻¹ (Table 5).

Table 2. Distribution of volume by different log grades at harvest and weighted mean log values per Douglas-fir MBF used in present value calculations.

	Log value per MBF, US\$	Percent of total volume	Weighted mean value per MBF, US\$
Stand: CR-WA			
Chip-and-saw	187	2	599
Special mill	700	30	
Pulp logs	107	1	
#2 sawmill	605	35	
#3 sawmill	550	24	
#4 sawmill	525	8	
Stand: CR-OR			
Chip-and-saw	187	4	533
Pulp logs	107	2	
#2 sawmill	605	26	
#3 sawmill	550	48	
#4 sawmill	525	20	
Stand: WC-OR			
Chip-and-saw	187	5	517
Pulp logs	107	2	
#2 sawmill	605	1	
#3 sawmill	550	69	
#4 sawmill	525	23	
Stand: WC-WA			
Chip-and-saw	187	6	517
Pulp logs	107	2	
#2 sawmill	605	6	
#3 sawmill	550	63	
#4 sawmill	525	24	

Note: MBF, thousand board feet.

Discussion

Economic impacts of black bear damage

Wildlife damage is an ongoing concern for intensively managed timber resources, and tools are needed to improve assessment of damage impacts. Our approach and estimates of economic loss to black bear damage advanced existing methods and estimates by including the additional impacts of partially girdled trees and accounting for loss based on the severity of individual-tree damage. Our two damage scenarios reflected how different landowners might interpret the losses that they incur from severe black bear damage on their lands. In our salvage scenario, damaged stands retained 84%–96% of the value of undamaged stands. In our total loss scenario, losses were, on average, four times greater, and black bear damaged stands retained 54%–83% of the value of undamaged stands (Table 5). These economic losses can be transformed into the perspective of average timber management costs (Table 6). In the salvage scenario, losses from black bear damage equaled the costs for landowners to prepare and plant 5–22 ha of industrial timberland. In the total loss scenario, losses from black bear damage equaled the costs for landowners to prepare and plant 17–66 ha of industrial timberland. Losses under the total loss scenario also were equivalent to the costs required to pre-commercially thin 51–195 ha of industrial timberland. For small landowners, the profits from harvesting timber might be applied toward the management of other timber stands on their lands. If landowners are relying on harvest profits to fund ongoing intensive management of other stands among their lands, black bear damage may hinder the ability to complete concurrent intensive management of other stands. Moreover, if landowners have already expended funds on preventive management of black bears, then future losses may be even greater if timber stands continue to incur severe damage.

Table 3. Stand-level details for each study site in western Oregon and Washington, 2015.

Stand	Age	Size, ha	Site index	DBH (SE), cm	Height (SE), m	Elevation, m	TPH	Plots
CR-WA	17	15	132	18.3 (0.041)	11.5 (0.155)	170–280	936	37
CR-OR	29	8	131	27.4 (0.124)	22.1 (0.475)	380–520	642	20
WC-OR	15	6	115	17.3 (0.052)	10.7 (0.269)	380–1750	724	15
WC-WA	33	13	111	24.1 (0.099)	15.7 (0.452)	790–920	684	32

Note: DBH, diameter at breast height; TPH, stand density in trees per hectare; Plots, number of 0.04 ha sample plots surveyed in each stand; SE, standard error.

Table 4. Volume at harvest and present stand values for each of four sample stands under two bear damage scenarios and an undamaged scenario.

Stand	Harvest age, years	Undamaged		Salvage scenario		Total loss scenario	
		Total volume at harvest, m ³	Present value of stand, US\$	Total volume at harvest, m ³	Present value of stand, US\$	Total volume at harvest, m ³	Present value of stand, US\$
CR-WA	62	23 536	250 072	21 309	225 542	16 720	175 407
CR-OR	44	5 307	181 854	5 091	174 533	4 440	150 049
WC-OR	55	4 335	42 659	3 686	35 812	2 486	23 131
WC-WA	63	7 117	124 280	6 794	118 142	5 375	92 867

Table 5. Economic losses to bear damage for each of four sample stands under two bear damage scenarios.

Stand	% damaged	Salvage scenario				Total loss scenario		
		TPH damaged	Economic loss, US\$	Loss per hectare, US\$	Value of undamaged stand, %	Economic loss, US\$	Loss per hectare, US\$	Value of undamaged stand, %
CR-WA	16.2	148	24 530	1635	90	74 666	4978	70
CR-OR	8.5	55	7321	915	96	31 805	3976	83
WC-OR	42.4	310	6846	1141	84	19 528	3255	54
WC-WA	13.5	93	6138	472	95	31 413	2416	75

Note: TPH, stand density in trees per hectare.

Table 6. Average cost per hectare for common timber management activities in western Oregon and Washington, 2015.

Management activity	Cost per hectare, US\$
Site preparation	644.94
Site planting	480.13
Decadal management	156.43
Pre-commercially thinned	383.26
Fertilization	179.18

Implications for management

Black bears are valued highly in Oregon and Washington as game animals and as an important wildlife species by the general public (Oregon Department of Fish and Wildlife 2012). For those areas that continue to experience severe damage, additional management considerations are suggested. Damage may be mitigated by continued trapping efforts in these stands with emphasis on selective removal of damaging black bears. There is opportunity for private landowners to team up with local hunters by providing access and location information for black bear damage on their lands. Supplemental feeding also has been used in select areas to reduce bear damage to conifers (Ziegeltrum 2004). For areas that seem to experience higher levels of damage after thinning or after fertilization, it may be beneficial to delay thinning or fertilization until stands are past the most susceptible age for peeling (Barnes and Engeman 1995; Schmidt and Gourley 1992). Management costs could be quantified and contrasted with projected losses to bear damage. Our methodology can be incorporated into forest planning to help landowners assess whether the volume losses incurred from black bear damage can be offset by management techniques such as delayed thinning, depredation hunting, and supplemental feeding.

The four stands that we sampled contained what is considered severe black bear damage (>25 black bear damaged trees per hectare), yet covered a range of severities, from 8.5% to 42% damage. This understanding of economic losses associated with a range of severities will allow landowners to make economically favorable planning decisions for managing both black bears and timberlands to prevent severe black bear damage in the future and meet forestland management goals. On-the-ground monitoring of black bear damage frequency and severity across western Oregon and Washington at the stand level will provide an understanding of these changes over time as a result of black bear and forest management decisions. Although demonstrated using data from western Oregon and Washington, our approach and conceptual framework incorporates variables and methods that are applicable and transferrable to forested landscapes where black bear damage occurs in other locations or for other wildlife species known to damage standing timber.

Opportunities for future research

Our growth models and economic models provide opportunities for future research on black bear damage impacts. First, our estimates represented a snapshot in time of black bear damage observed in a single year of the timber rotation. We do not currently have the ability to accurately predict what levels of new damage, if any, will occur in these stands over the next 15–45 years. Additionally, in this case, we were primarily focused on understanding losses in these stands in their current state. Therefore, our models account only for black bear damage that has occurred in these stands between stand initiation (i.e., time of planting) and 2015. Repeated observations of the same plots over multiple years would improve future estimates of economic loss by black bears.

Another opportunity for future research is developing a tool within forest growth and yield models that simulates and cap-

tures complex tree growth nuances that are associated with black bear damage. Black bear damage in our models was treated as analogous to a thinning treatment. When removing black bear killed trees, the model treated these trees as if killed that year. That treatment in turn affects the predicted growth of surviving trees in the model. In reality, however, our field data revealed that the majority of the black bear killed trees had been dead or dying for multiple years. As a result, the remaining surviving trees likely had already responded to relinquished resources and growing space around them. Additionally, the model simulates thinning uniformly across the stand, whereas black bear damage imposes a relatively clustered pattern of thinning. The clustered pockets of dead trees resulting from black bear damage initiate a different response in the future growth of the stand than uniformly spaced mortality. With the development of a black bear damage tool, modeling damage impacts over time would better reflect forest response to black bear damage and perhaps could be applied to timber damage patterns resulting from other wildlife species.

A final opportunity for future research lies in understanding mortality rates and growth rates of damaged trees over a larger temporal scale. Miller et al.'s (2007) study of the growth of black bear damaged trees found that partially girdled trees averaged 29%–33% faster diameter growth than nearby undamaged trees. Additionally, Harrington's ongoing study (USDA Forest Service, unpublished data) of tree growth 8 years following simulated bole damage showed an increase in diameter growth of partially girdled trees, as well as initial decreases in height growth. We chose not to account for changes in height or diameter growth of damaged trees in this initial model because the 8 years of reported values were not convincingly sufficient to project 15–45 years into the future. Instead, to focus the scope of our study, we decided that it was more imperative to account for tree mortality over time from black bear damage wounds. Understanding damaged tree mortality and growth rates for a full timber rotation will provide more accurate estimates of losses to black bear damage at a time scale that more precisely reflects forestland management.

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